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Effect of Oil Prices on Exchange Rate Movements in Korea and Japan Using Markov Regime-Switching Models

Suyi Kim [1], So-Yeun Kim [1] and Kyungmee Choi [2,*]

[1] College of Business Management, Hongik University, Sejong 30016, Korea; suyikim@hongik.ac.kr (S.K.); s22kim@hongik.ac.kr (S.-Y.K.)
[2] College of Science and Technology, Hongik University, Sejong 30016, Korea
* Correspondence: kmchoi@hongik.ac.kr; Tel.: +82-44-860-2237

Received: 19 July 2020; Accepted: 24 August 2020; Published: 26 August 2020

Abstract: We examined the effects of oil prices along with fundamental economic variables on exchange rate movements in the Korean and Japanese foreign exchange markets, using two-regime Markov Regime Switching Models (MRSMs) over the period from January 1991 to March 2019. We selected the best MRSMs explaining their exchange rate movements using the Maximum Log-Likelihood and Akaike Information Criteria, and analyze effects of oil prices on their exchange rates based on the selected best MRSMs. We consider two regimes, regime 1 with high-volatility and regime 2 with low-volatility. In Korea, two apparent regimes are observed, and unstable regime 1 consists of two distinct prolonged periods, the 1997 Asian Financial Crisis and the 2008 Global Financial Crisis. Meanwhile in Japan, no evident prolonged regimes are observed. Rather, the two regimes occasionally alternate. Oil prices influence exchange rate movements in regime 2 with low-volatility in Korea, while they do not influence exchange rate movements in either regimes in Japan. The Japanese foreign exchange market is more resistant to external oil price shocks because the Japanese industry and economy has less dependence on oil than Korea.

Keywords: oil prices; exchange rates; trade balance; industrial production index; Markov regime-switching model

1. Introduction

While the share of oil in the world's energy supply is slowly decreasing, oil is still the largest primary energy source. According to the International Energy Agency (IEA, 2019) [1], though the share of oil in the world total primary energy supply (TPES) fell from 44% to 32% between 1971 and 2017, it was still the dominant fuel and accounted for 32% in world TPES in 2017, followed by 27% coal, and 22% natural gas. In the transportation sector, the largest oil consuming sector with over one third of the overall total final consumption (TFC), oil consumption remained dominant and accounted for 93% in organization for economic cooperation and development (OECD) countries, despite the rapid growth of biofuels and electricity.

Despite the changes in the global energy structure, oil prices are steadily increasing, serving as price measurement of other energy sources, such as natural gas and coal. Thus, as a result of fluctuations in oil prices, the volatility of the national economy has been growing in countries largely dependent on oil imports. Simply put, volatility of exchange rates is strongly related to volatility of oil prices, which has been an important research topic in energy economy.

Previous studies on the relationship between oil price and exchange rates, using in-sample modeling, include Amano and Van Norden [2], Amano and Van Norden [3], Chaudhuri and Daniel [4],

Chen and Chen [5], Lizardo and Mollick [6], Basher et al. [7], Aloui et al. [8], Chen et al. [9], Volkov and Yuhn [10], Chen et al. [11], Basher et al. [12], Yang et al. [13], Kim et al. [14], and so on.

Focusing on the papers with in-sample modeling, Amano and Van Norden [2] examined the relationship between the real domestic oil price and the real effective exchange rates in Germany, Japan, and the US, over the period from January 1973 to June 1993. They found strong evidence of granger-causality from the price of oil to the real exchange rate, with no evidence to indicate the reverse. Amano and Van Norden [3] explored the link between the oil prices and the US real exchange rates over the period from February 1972 to January 1993. They found a stable link between oil price shocks and the US real effective exchange rate over the post-Bretton Woods period, and suggested that oil prices may be the dominant source of real US exchange rate shocks. Chen and Chen [5] investigated the long-run relationship between real oil prices and real exchange rates by using a monthly panel of G7 countries from January 1972 to October 2005. They showed that real oil prices may have been the dominant source of real exchange rate movements, and found the forecasting power of real oil prices on future real exchange returns using panel predictive regression. Adding oil prices to the basic monetary model of exchange rate determination, Lizardo and Mollick [6] examined the role of oil price shocks in determining the value of the US dollar against major currencies from the 1970s to 2008. They found that oil prices significantly affected the movements of the US dollar. Basher et al. [7] investigated the dynamic relationship between oil prices and exchange rates in emerging economies using structural vector autoregressive model over the period from January 1988 to December 2008. They noted that exchange rates respond to movements in oil prices and a positive oil price shock leads to an immediate drop in the trade-weighted exchange rates.

Aloui et al. [8] examined the conditional dependence structure between crude oil prices and US dollar exchange rates over the period from 2000 to 2011, using a copula-Generalized Auto-regressive Conditional Heteroscedasticity (GARCH). They observed significant and symmetric dependence for almost all the considered oil price-exchange rate pairs. Furthermore, an increase in the oil price was associated with the depreciation of the US dollar.

Volkov and Yuhn [10] explicitly investigated the effects of oil price shocks on exchange rate movements in five major oil-exporting countries: Russia, Brazil, Mexico, Canada, and Norway from February 1998 to August 2012. Evidence showed a strong association between the volatility of exchange rates and oil price shocks in Russia, Brazil, and Mexico, but a weak one in Norway and Canada. They also showed that an increase in oil prices leads to the appreciation of the local currency (that is, a fall in the dollar exchange rate) in all countries, ceteris paribus. Chen et al. [11] investigated the impacts of oil price shocks on the bilateral exchange rates of the US dollar against currencies in 16 OECD countries over the period from August 1992 to December 2011. There was empirical evidence that the dollar exchange rates were affected by oil price shocks, the responses differed depending on whether the changes in oil prices were driven by supply or aggregate demand. Oil price shocks can explain about 10~20% of long-term variations in exchange rates. Basher et al. [12] investigated the impact of oil shocks on real exchange rates for nine oil exporting and importing countries until February 2014 using Markov-switching model. They showed that oil shocks in at least one state in each country had a statistically significant impact on exchange rates, providing more substantial evidence of oil shocks affecting real exchange rates.

Yang et al. [13] examined the influence of crude oil prices on the exchange rates of 10 oil importing and exporting countries over the period from January 1999 to December 2014, using Wavelet coherence analyses. They found that the crude oil price was a significant determining factor in the exchange rate of oil-exporting countries compared to the oil-importing countries. A negative relationship was also confirmed between the crude oil price and the exchange rates for the oil-exporting countries, whereas the relationship was uncertain for the oil-importing countries. Kim et al. [14] investigated the effects of oil prices on the regime shift behavior of the Korean exchange rates against the US Dollar from January 1991 to March 2019, using Markov regime switching model. They discovered that Korean exchange

rates were significantly influenced by oil prices in the regime with high-volatility, but not in in the one with low-volatility.

There exists a lot of literature on out-of-sample exchange rate modeling using commodity prices including oil prices. Rossi [15] surveys the literature on out-of-sample exchange rate predictability and has a section on commodity prices, which contains other references. Representatively, Ferraro et al. [16] and Chen and Rogoff [17] investigated whether oil prices affect exchange rates. Ferraro et al. [16] examined the reliability and stability of the out-of-sample relationship between oil prices and the Canadian/US dollar exchange rates. They found the existence of a short-term relationship at the daily frequencies, especially when using contemporaneous oil prices, but little relationship at the monthly/quarterly frequencies. Chen and Rogoff [17] further investigated the real exchange rate behavior in three countries (Australia, Canada, and New Zealand), where primary commodities including oil constitute a significant share of their exports. They found that the US dollar prices of their commodities have a strong and stable influence on their real exchange rates, particularly Australia and New Zealand, which is consistent with predictions of standard theoretical models.

In most of the studies above, oil prices have a statistically significant effect on exchange rates, and in some studies, there appears to be granger-causality from oil prices to exchange rates. However, the extent to which oil prices affect exchange rates differs depending on the countries, periods being analyzed, and the analysis methods.

The empirical methods used in the previous studies on in-sample modeling include the fully modified ordinary least squares (FMOLS) with cointegration technique (Amano and Van Norden [2], Chen and Chen [5]), the error correction model (ECM) (Amano and Van Norden [3], Chaudhuri and Daniel [4]), the vector error correction model (Lizardo and Mollick [6]), Structural vector autoregression (Basher et al. [7], Chen et al. [9]), GARCH (Chen, Chodhry, and Wu [9], Volkov and Yuhn [10]), and copula-GARCH (Aloui et al. [8]). Recently, methodologies such as the Markov-Regime Switching Model (MRSM) (Basher et al. [12]), Kim et al. [14]) and Wavelet coherence analyses (Yang et al. [13]) have been introduced.

As discussed above, although the subjects, periods and analysis methods vary across studies, oil prices have significant effect on exchange rates in most studies and play an important role in the exchange rates determination.

This study differs from the previous studies in the following ways. First, the previous studies on exchange rate movements that used MRSM did not consider trade balances as an influencing factor on exchange rates. This study includes the trade balances in explanatory variables. In this paper, we extended Kim et al. [14] in order to examine the impact of oil prices on exchange rates against the US dollar, by taking account of trade balances in addition to interest rates, consumer price index (CPI), and industrial production index (IPI) as an influencing factor on the exchange rates in Korea and Japan.

Second, most of the previous analyses explored a few developed countries including the US, the United Kingdom, or oil-exporting countries including Brazil, Canada, Mexico, Norway, and Russia. Basher et al. [7] and Yang et al. [13] included Korea and Japan in their analyses, but there were no studies that analyzed the exchange rate markets of Korea and Japan in-depth. Although both Korea and Japan import 100% of their consumed oil, the impact of oil prices on foreign exchange markets is expected to be different in each country, due to differences in the industrial structures and fundamental economic situation. According to IEA [1], the share of crude oil in TPES in 2017 is 37.1% in Japan, and 54.2% in Korea. In the final energy consumption of Japan, 46% of oil products were used in the transportation sector, 27% were used as energy and non-energy raw materials in the petrochemical industry, and the remaining 16% were used in residential, commercial, and public services. In Korea, 36% of oil products were used in the transportation sector, 52% were used as energy and non-energy raw materials in the petrochemical industry, and the remaining 5.7% were used in the residential, commercial, and public services. In terms of oil demand, Korea has a much higher share of the demand for industry than Japan. In addition, due to these differences in the oil supply and demand structure of these two countries, the impact of oil price movements on exchange rate movements is expected

to be different. This study compares the effect of oil prices on the exchange rates in each foreign exchange market.

Third, this study employs the MRSMs in the methodology. Basher et al. [7] and Kim et al. [14] used an econometric model that does not consider regime change. Basher et al. [7] analyzed the impact of three oil shocks on exchange rates by classifying oil shocks into oil demand shock, oil supply shock, and global economic shock (oil prices). They did not directly take into account macroeconomic variables such as interest rates, income, and price level. Their study was unable to directly grasp the effect of interest rates, income, and price level on exchange rates. Kim et al. [14] analyzed the effects of oil prices on exchange rates along with interest rates, income and price level. However, trade balance was not included as an influencing factor on exchange rates, and the analysis was limited to Korea. Furthermore, other than Kim et al. [14], the other studies focused on the direct effect of explanatory variables on exchange rates without considering the movements of explanatory variables. However, the movements in the exchange rate can be more concretely assessed through the movements in the explanatory variables under the regime switching model.

The purpose of this study is to identify the best MRSM model in Korea and Japan and examine the effects of oil price shocks on exchange rates movements in each country using the identified best two-regime MRSMs (Hamilton, [18]) for each country, respectively. Some previous studies also analyzed the movements of the exchange rate using the MRSM model, but the specific model establishment process and explanatory variables affecting the exchange rate are quite different from this study. Therefore, the results derived from this study seem to have results different from previous studies. In this study, we analyzed exchange rates movement for both Korea and Japan, along with the trade balances in addition to CPI, IPI, interest rates, and oil prices. The time span is based on monthly data collected from January 1991 to March 2019.

The rest of the paper is organized as follows. In Section 2, we prepared the response variable and explanatory variables, proposed the two-regime MRSMs, and provided a review of model selection criteria methods. In Section 3, we presented the empirical model selection procedure and estimates of the selected MRSM. In Section 4, we discussed the statistical validity of the selected MRSM with its assumptions and the final conclusions are presented.

2. Data and Methods

2.1. Data

This study aimed to analyze how much oil price shocks affect exchange rate movements. First, it is necessary to identify the fundamental economic factors that affect the exchange rates. Our empirical model is based on the monetary model of exchange rates determination. This was the dominant exchange rates model in the early 1970s, and henceforth remained an important exchange rate paradigm (Frenkel [19]; Mussa [20–22]; and Bilson [23]). According to the monetary model for determining exchange rates, exchange rates are determined by the relative money supply and demand of two corresponding countries. The money supply is exogenously determined by the policy makers of each country, whereas the money demand is determined by the price and income level, interest rates and other influencing factors of the corresponding countries. According to the seminal empirical work by Meese and Rogoff [24,25] the exchange rates are mostly influenced by the differences in macroeconomic variables such as money supply, output, interest rates, inflation rates, and trade balances between two corresponding countries. Since this seminal paper, many empirical studies have been conducted on the determination of exchange rates. Recently, Cheung et al. [26] compared various models on predicting exchange rates. The compared models are uncovered interest rate parity (IRP), relative purchasing power parity (PPP), sticky price monetary model (SPMM), behavioral equilibrium exchange rate (BEER) model, Taylor rule fundamentals (TRF), real interest differential (RID), sticky price monetary model augmented by risk and liquidity factors (SPMA), and yield curve slope (YCS). Each model shows its strengths and weaknesses in terms of various criteria, but there is no dominant model that

fits every criterion. Our model seems to be close to the TRF and SPMA models, in line with Meese and Rogoff [24,25].

The recent work by Volkov and Yuhn [10] pointed out some relevant factors affecting the exchange rates of some countries in comparison with the US. The factors are differentials of interest rates, production, and inflation rates between two corresponding countries. Along with these factors, we added the trade balances of the corresponding countries, as significant fundamental factors influencing the exchange rates as suggested by Meese and Rogoff [24,25]. However, we excluded the money supply variable to avoid any latent multicollinearity among the money supply and other variables which affect the exchange rate. In addition, oil prices are added as a factor affecting the exchange rate.

Considering the previous work and results, this study identifies fundamental economic variables that determine the exchange rates of each country, comparing this with the US. For each country, the five economic fundamental factors considered are interest rates differences, production differences, inflation rates differences between the examined country and the US, trade balance of the examined country, and trade balance of the US. Along with these five factors, oil prices are also added to the model. Here, production is represented by IPI and inflation is represented by CPI.

2.1.1. Responsible Variables

The monthly exchange rates, E_t, are defined as the money value of the country needed to purchase one US dollar at time t. The response variable at a certain time t is defined as the monthly logarithmic changes in the exchange rates in comparison with the ones from previous months as follows (Ayodeji, [27]):

$$\Delta \log E_t = \log(Exchange\ Rate_t) - \log(Exchange\ Rate_{t-1}) = \log\left(\frac{Exchange\ Rate_t}{Exchange\ Rate_{t-1}}\right) \quad (1)$$

Then $\Delta \log E_t$ is supposed to lie in one of the two regimes S_t, where S_t is 1 or 2. In equity markets, the logarithmic return rates are a Brownian motion (Osborne, [28]), and thus, we assume that $\Delta \log E_t$ follows a normal distribution.

2.1.2. Explanatory Variables

There are four steps to prepare explanatory factors.

Step 1

For each country in Korea or Japan, the influencing economic factors on exchange rates are denoted as oil prices(OIL), interest rates(INT), consumer price indices(CPI), industrial production indices(IPI), trade balances(TB): OIL_t, $INT_t^{country}$, $CPI_t^{country}$, $IPI_t^{country}$, and $TB_t^{country}$ where t denotes time. For the US, the same explanatory variables are denoted as INT_t^{USA}, CPI_t^{USA}, IPI_t^{USA}, and TB_t^{USA}.

Step 2

As the exchange rate means the currency value of the corresponding country in relation to the US dollar, we define $DINT_t$, $DCPI_t$, and $DIPI_t$ as follows:

$$\begin{aligned} DINT_t &= INT_t^{country} - INT_t^{USA} \\ DCPI_t &= CPI_t^{country} - CPI_t^{USA} \\ DIPI_t &= IPI_t^{country} - IPI_t^{USA} \end{aligned}$$

$DINT_t$, $DCPI_t$, and $DIPI_t$ are difference of interest rates, CPIs, and IPIs between the examined country and the US respectively. We use OIL_t as it is because its prices are the same for all countries.

Step 3

We define the time differentials ΔOIL_t, $\Delta DINT_t$, $\Delta DCPI_t$, $\Delta DIPI_t$, $\Delta TB_t^{country}$, and ΔTB_t^{USA} as follows:

$$\Delta OIL_t = OIL_t - OIL_{t-1} \tag{2}$$

$$\Delta DINT_t = DINT_t - DINT_{t-1} \tag{3}$$

$$\Delta DCPI_t = DCPI_t - DCPI_{t-1} \tag{4}$$

$$\Delta DIPI_t = DIPI_t - DIPI_{t-1} \tag{5}$$

$$\Delta TB_t^{country} = TB_t^{country} - TB_{t-1}^{country} \tag{6}$$

$$\Delta TB_t^{USA} = TB_t^{USA} - TB_{t-1}^{USA} \tag{7}$$

Note that Equations (3)–(5) are calculated from two differences. The first difference is between the examined countries and the US and the second difference is between time t and time $(t-1)$. We call them differentials since they are approximate derivatives.

Step 4

The differentials ΔOIL_t, $\Delta DINT_t$, $\Delta DCPI_t$, $\Delta DIPI_t$, $\Delta TB_t^{country}$, and ΔTB_t^{USA} can be in different measurement scales. Since the estimates of the parameters in a large scale can overwhelm those in a small scale, we standardize these differentials by subtracting their means and dividing with their standard deviations, and call the standardized variables as ΔOIL_t^*, $\Delta DINT_t^*$, $\Delta DCPI_t^*$, $\Delta TB_t^{country*}$, and ΔTB_t^{USA*}, respectively. We leave the response variable without standardizing because we want to observe volatilities as they are.

Except for the oil prices and the trade balances of Korea, Japan, and the US, all monthly data used in this paper were collected from the OECD data set (OECD.stat) from January 1991 to March 2019. The short-run interest rates (%) were collected from the Monthly Monetary and Financial Statistics data set of the OECD. The consumer price indices (with the index of 2015 being 100) were collected from the Consumer Price Indices (CPIs) database of the OECD, and the monthly industrial production indices (with the index of 2015 being 100) were collected from the Production and Sales database of the OECD. The Asian oil prices in the US dollar are the Cost Insurance and Freight (CIF) oil importing prices and were collected from the Korea Energy Statistical Information System of the Korea Energy Economics Institute. The monthly trade balances of the countries are from 'Trade Statistics Service' (https://www.bandtrass.or.kr/index.do) in Korea.

2.2. The Markov Regime Switching Model

The two-regime Markov Switching model by Hamilton [15] is applied since economic data often reveals two or more circumstances. The MRSMs divides the whole period into the two regimes. Regime 1 is a set of high-volatility periods and regime 2 is another set of low-volatility periods. Regime 1 is identified as unstable periods and regime 2 is identified as stable periods. The processes of exchange rates switch between Regime 1 and Regime 2 according to Markov transition probabilities. The process is classified to Regime 1 if its filtered probability of belonging to Regime 1 is greater than 0.5.

Let us define $s_t = 1$ for regime 1 with high-volatility and $s_t = 2$ for regime 2 with low-volatility. Then the two-regime MRSM is defined as follows:

$$\begin{aligned}\Delta \log E_t|s_t = \beta_{0s_t} + \beta_{1s_t}\Delta \log E_{t-1} + \beta_{2s_t}\Delta OIL_t^* + \beta_{3s_t}\Delta DINT_t^* + \beta_{4s_t}\Delta DCPI_t^* + \\ \beta_{5s_t}\Delta DIPI_t^* + \beta_{6s_t}\Delta TB_t^{country*} + \beta_{7s_t}\Delta TB_t^{USA*} + \varepsilon_t|s_t\end{aligned} \tag{8}$$

where $\varepsilon_t|s_t \sim N\left(0, \sigma_{s_t}^2\right)$. The Markov transition probabilities are defined as:

$$p_{ij} = P(s_{t+1} = j|\, s_t = i),\ i = 1,\ 2,\ j = 1,\ 2 \tag{9}$$

where p_{ij} is the probability of transition from regime i to regime j and $p_{i1} + p_{i2} = 1$, for $i = 1, 2$. The regime with greater σ_i^2 becomes regime 1 with high-volatility and the regime with smaller σ_i^2 becomes regime 2 with low-volatility.

The parameter space Θ is:

$$\Theta = \left\{\beta_{0s_t},\ \beta_{1s_t}, \beta_{2s_t},\ \beta_{3s_t}, \beta_{4s_t}, \beta_{5s_t}, \beta_{6s_t}, \beta_{7s_t},\ \sigma_{s_t}^2,\ p_{12},\ p_{21}\right\},\ \mathrm{s_t} = 1\ or\ 2. \tag{10}$$

The oil prices, INTs, CPIs, IPIs, and TBs do not switch. We apply the msmFit function (Sanchez-Espigares and Jose, [29]).

Changing from $\Delta DINT_t^* = 0$ to $\Delta DINT_t^* = 1$ while all the others are fixed, $\Delta \log E_t$ changes by β_{2s_t}. In other words, if the differential of the difference of INTs between the examined country and the US change from its mean by 1 standard deviation, then their log-differentials of exchange rates change by β_{2s_t}. Similar interpretation can be applied to the other explanatory variables. For simple and clear interpretation, we use "changes" for the notation Δ.

2.3. Model Selection Criteria

The traditional model selection criterion is the Maximum Log-Likelihood (MLL) function. In general, the model with greater MLL is better, although we need a precise test. The null hypothesis H_0 assumes a restricted model and the alternative hypothesis H_1 assumes the more general model. Let MLL_1 be the MLL under H_1 and MLL_0 be the MLL under H_0. Under H_i, d_i is said to be the dimension of the parameter space or the number of estimated parameters. In a large sample, the difference in MLLs asymptotically follows a chi-square distribution as follows:

$$\Delta(-2MLL) = 2(MLL_1 - MLL_0) \rightarrow \chi^2(d_1 - d_0) \tag{11}$$

The rule of selection is to choose the more general model if the difference in MLLs between the two selected models is significant. By adding or removing one variable, the change in the degrees of freedom is 2 in the two-regime MRSM, where one variable corresponds to two parameters since it fits a different autoregressive model in each regime.

Besides, we use the Akaike information criterion (AIC) which includes a penalty on increment in the dimension of the parameter space. The AIC is defined as:

$$AIC = -2MLL + 2n_{par} \tag{12}$$

where n_{par} is the dimension of the parameter space in the model. "The model with smaller AIC is better." (Akaike [30,31]; Pinheiro and Bates, [32]; and Rice [33]). The AIC is a primary model selection criteria in Artificial Intelligence.

2.4. Model Selection Methods

We can approach selecting the best model for explaining the exchange rate movements by selecting the significant explanatory variables among the six provided ones. We suggest the following two methods. We use 0.10 as the significance level.

- **Model Selection Method 1**: Stepwise variable selection in the MRSM

This method is the traditional stepwise variable selection, which has the exact distribution theory to test addition or removal of variables. The starting MRSM includes the most significant explanatory variable with the greatest MLL or the smallest AIC. We add a new variable if it significantly improves MLL with $\Delta(-2MLL) > \chi_{0.10}(2) = 4.61$. On the other hand, we test the removal of each variable which is already included in the model. We continue the selection procedure until there are no more variables to be added or removed. This method should be performed manually since there is no sepwise function available for msmFit in R [34].

- **Model Selection Method 2**: Stepwise variable selection with the full AR(1) model and backward elimination in the MRSM

This method is combination of traditional stepwise variable selection in the full autoregressive model and backward elimination in the MRSM, which provides a shortcut of the method 1. To be more specific, we first start with the full autoregressive model without considering regimes. Second, the stepwise selection method is applied to the full autoregressive model based on the AIC. For this, stepAIC function is used (Venables and Ripley, [35]) in R 3.3.1. Third, the MRSM is fitted with those explanatory variables in the finally selected autoregressive model by stepAIC. Fourth, each variable in the MRSM model is tested on whether its removal is significant. The two model selection methods can complement one another.

3. Results and Discussion

The two proposed model selection methods are applied to foreign exchange markets of Korea and Japan, both of which import 100% of their oil. We investigate how the impact of oil prices on exchange rates varies in Korea and Japan, using MRSMs.

3.1. Korea

3.1.1. Model Selection

According to the model selection method 1, we select a model that best explains the changes in the exchange rates of Korea. In step 1, we started with models having only one explanatory variable from 1(1) to 1(6) in Table 1, where each model includes autoregressive terms of exchange rates. Among the six models with only one explanatory variable, model 1(2) is selected to be the best based on the greatest MLL or the smallest AIC as follows:

$$\Delta \log E_t|s_t = \beta_{0s_t} + \beta_{1s_t}\Delta \log E_{t-1} + \beta_{3s_t}\Delta DINT_t^* + \varepsilon_t|s_t. \tag{13}$$

Table 1. Model Selection Process with Method 1 in Korea.

Steps	Model	Explanatory Variables	AIC	MLL	Criterion
1	1(1)	ΔOIL_t^*	−1741.163	876.582	-
	1(2)	$\Delta DINT_t^*$	−1746.283	879.141	greatest MLL
	1(3)	$\Delta DCPI_t^*$	−1743.35	877.675	-
	1(4)	$\Delta DIPI_t^*$	−1739.465	875.733	-
	1(5)	ΔTB_t^{Korea*}	−1741.413	876.707	-
	1(6)	ΔTB_t^{USA*}	−1737.444	874.722	-
2	2(1)	$\Delta OIL_t^*, \Delta DINT_t^*$	−1747.878	881.939	$\Delta(-2MLL) = 5.60$
	2(2)	$\Delta DINT_t^*, \Delta DCPI_t^*$	−1747.731	881.865	-
	2(3)	$\Delta DINT_t^*, \Delta DIPI_t^*$	−1744.495	880.247	-
	2(4)	$\Delta DINT_t^*, \Delta TB_t^{Korea*}$	−1747.538	881.769	-
	2(5)	$\Delta DINT_t^*, \Delta TB_t^{USA*}$	−1742.41	879.205	-
3	3(1)	$\Delta OIL_t^*, \Delta DINT_t^*, \Delta DCPI_t^*$	−1748.303	884.151	-
	3(2)	$\Delta OIL_t^*, \Delta DINT_t^*, \Delta DIPI_t^*$	−1746.846	883.423	-
	3(3)	$\Delta OIL_t^*, \Delta DINT_t^* \Delta TB_t^{Korea*}$	−1748.597	884.299	$\Delta(-2MLL) = 4.72$
	3(4)	$\Delta OIL_t^*, \Delta DINT_t^*, \Delta TB_t^{USA*}$	−1743.879	881.939	
4	2(6)	$\Delta OIL_t^*, \Delta TB_t^{Korea*}$	−1741.307	878.654	-
	2(7)	$\Delta DINT_t^*, \Delta TB_t^{Korea*}$	−1747.538	881.769	-
	2(8)	$\Delta OIL_t^*, \Delta DINT_t^*$	−1747.878	881.939	$\Delta(-2MLL) = 4.72$
5	4(1)	$\Delta OIL_t^*, \Delta DINT_t^*, \Delta DCPI_t^*, \Delta TB_t^{Korea*}$	−1747.999	886.000	$\Delta(-2MLL) = 3.40$
	4(2)	$\Delta OIL_t^*, \Delta DINT_t^*, \Delta DIPI_t^*, \Delta TB_t^{Korea*},$	−1747.281	885.640	$\Delta(-2MLL) = 2.68$
	4(3)	$\Delta DINT_t^*, \Delta TB_t^{Korea*}, \Delta TB_t^{USA*}$	−1744.603	884.302	$\Delta(-2MLL) = 0.01$

Every model includes an autoregressive term.

In step 2, we add a new variable into the model and see if it significantly increases MLL. Adding one variable at a time, the difference in the degrees of freedom between model 1(2) and the other models to be tested is 2 since the added variable has two coefficients, one in Regime 1 and the other in Regime 2. Thus, if $\Delta(-2MLL) > \chi^2_{0.10}(2) = 4.61$ the corresponding variable should be added into the model. The whole process is presented in Table 1. Oil is added and then model 2(1) is selected since $\Delta(-2\text{MLL}) = 5.60 > 4.61$. Model 2(1) is as follows:

$$\Delta \log E_t|s_t = \beta_{0s_t} + \beta_{1s_t}\Delta \log E_{t-1} + \beta_{2s_t}\Delta OIL^*_t + \beta_{3s_t}\Delta DINT^*_t + \varepsilon_t|s_t. \tag{14}$$

Here, neither oil nor INTs can be eliminated.

In step 3, we repeat the test with model 2(1) and other three-explanatory variable models that include each of the variables besides oil and INTs. Model 3(3) including Korean TB is selected since $\Delta(-2MLL) = 4.72$ is greatest and significant. In step 4, removing each of oil, INTs, and Korean TB causes significant decrease in the MLL. Thus, all of them remain in the selected model 3(3). In step 5, we repeat the test model 3(3) against other four-explanatory variable models that include model 3(3). Model 4(1) is the model with the greatest MLL among the four-explanatory variable models including 3(3), but its $\Delta(-2MLL) = 3.40$ is not significant. The model 3(3) is the final model as follows:

$$\Delta \log E_t|s_t = \beta_{0s_t} + \beta_{1s_t}\Delta \log E_{t-1} + \beta_{2s_t}\Delta OIL^*_t + \beta_{3s_t}\Delta DINT^*_t + \beta_{6s_t}\Delta TB^{Korea*}_t + \varepsilon_t|s_t \tag{15}$$

According to the model selection method 2, in Korea, we fit the full autoregressive models without regimes and apply the stepwise variable selection method based on AIC. For this, we use stepAIC in R. In step 1, the model with $\Delta DINT^*_t$, ΔOIL^*_t, ΔTB^{Korea*}_t, and $\Delta DCPI^*_t$ is selected with the smallest AIC. Then model 4(1) is fitted as a starting MRSM.

In step 2, we try to remove each of the four explanatory variables, one at a time. $\Delta DCPI^*_t$ is removed since $\Delta(-2MLL) = 3.40 < 4.61$. Model 3(3) with $\Delta DINT^*_t$, ΔOIL^*_t, and ΔTB^{Korea*}_t is the best among the three explanatory variable models in Table 2. In step 3, we cannot reduce model 3(3) any further since all MLLs significantly decrease compared to that of model 3(3). The best model selected by the method 2 is the same as that by the method 1.

Table 2. Model Selection Process with Method 2 in Korea.

Steps	Model	Explanatory Variables	AIC	MLL	Criterion
1	4(1)	ΔOIL^*_t, $\Delta DINT^*_t$, ΔTB^{Korea*}_t, $\Delta DCPI^*_t$	−1747.999	886.000	Smallest AIC among all autoregressive models
2	3(1)	ΔOIL^*_t, $\Delta DINT^*_t$, $\Delta DCPI^*_t$	−1748.303	884.151	-
	3(3)	ΔOIL^*_t, $\Delta DINT^*_t$, ΔTB^{Korea*}_t	−1748.597	884.299	$\Delta(-2MLL) = 3.40$
	3(5)	$\Delta DINT^*_t$, $\Delta DCPI^*_t$, ΔTB^{Korea*}_t	−1747.632	883.816	-
	3(6)	ΔOIL^*_t, $\Delta DCPI^*_t$, ΔTB^{Korea*}_t	−1743.092	881.546	-
3	2(6)	ΔOIL^*_t, ΔTB^{Korea*}_t	−1741.307	878.654	$\Delta(-2MLL) = 11.29$
	2(7)	$\Delta DINT^*_t$, ΔTB^{Korea*}_t	−1747.538	881.769	$\Delta(-2MLL) = 5.06$
	2(8)	ΔOIL^*_t, $\Delta DINT^*_t$	−1747.878	881.939	$\Delta(-2MLL) = 4.72$

Every model includes an autoregressive term.

3.1.2. Empirical Estimation Using the Selected MRSMs

We regressed the selected MRSMs of model 3(3) in Tables 1 and 2. Figure 1 shows the estimated filtered probability for each time point belonging to one of the two regimes, regime 1 with high-volatility, or regime 2 with low-volatility. The upper plot shows the filtered probability of regime 1, and the lower plot shows those of regime 2. The two probabilities at each time point should sum up to 1. The time point with the estimated probability of regime 1 greater than 0.5 is said to be in regime 1 with high-volatility. Otherwise, we classify the time point to the regime 2 with low-volatility.

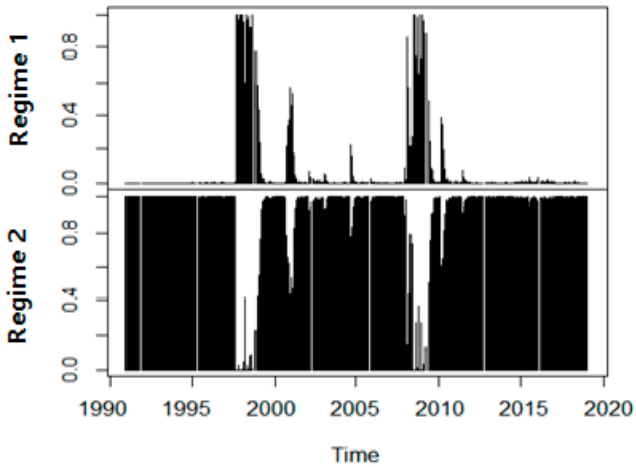

Figure 1. The filtered probabilities of belonging to regime 1 with high-volatility and regime 2 with low-volatility, estimated from the Markov-Regime Switching Model (MRSM) of the exchange rates along on oil prices, interest rates and trade balance of Korea. The upper plot shows regime 1, and the lower plot shows regime 2.

Most time points belong to regime 2. The regime 1 with high-volatility is composed of two distinct prolonged periods. The first period continued for 16 months from October 1997 to January 1999. The second period continued for 10 months, from August 2008 to May 2009. The first peak in high-volatility regime matches the Asian financial crisis which occurred in 1997. The second peak matches the global financial crisis which occurred in 2008. The Korean exchange rates went through great fluctuations during both periods. The first Asian financial crisis was longer and the negative impact on the Korean economy was greater than the second global financial crisis. This trend is also reflected in the exchange rates market.

In Table 3, the explanatory variables are examined to determine how they affect the exchange rates by regime in the selected best model 3(3). The parameters are estimated with 95% confidence interval and p-values of the estimates. The volatility of regime 1 with high-volatility ($\sigma_1 = 0.0615$) is about four times that of regime 2 with low-volatility ($\sigma_2 = 0.0146$). In regime 1 with high-volatility, the exchange rate movements are mostly influenced by the changes in the interest rates differences, and the coefficients of the autoregressive terms are not significant. Although the impact is small, at 10% significance level, the exchange rate movements are influenced by the changes in the trade balance of Korea, but not by those of the US, because Korea is a relatively small country compared to the US, in terms of economy. In regime 2 with low-volatility, the exchange rate movements are most significantly influenced by the changes in previous exchanges rates and their autoregressive terms at 1% significance level. The changes in the oil prices also influence the exchange rate movements at 5% significance level. However, the impact of oil prices on the exchange rate movements is relatively small compared to the impacts of their autoregressive terms.

It is observed that the foreign exchange markets behave quite differently depending on the stability of the economy. The oil prices affect the exchange rates only in the stable regime while the exchange rates are affected by both the interest rates and the trade balance of Korea in the unstable regime.

The transition probability from regime 2 to regime 1 is $p_{21} = 0.0845$ and the opposite transition probability is $p_{12} = 0.0089$, whose ratio p_{21}/p_{12} is 9.4944. This indicates that the low-volatility status of the market can transit more easily to high-volatility status if the explanatory variables get worse. The Korean foreign exchange market is susceptible to external shocks like the trade balance of Korea and the interest rates differences between Korea and the US when the market is unstable. The determination of coefficient R^2 is 0.4728 in regime 1 and R^2 is 0.1182 in regime 2. This means that the MRSMs is better fitted in regime 1 with high-volatility than in regime 2 with low-volatility.

Table 3. Parameter Estimates of the Selected MRSM in Korea.

Regime	Parameters	Estimates	95% CI	*p*-Value
Regime 1 with high-volatility	Intercept (β_{01})	0.0184	(−0.0057, 0.0425)	0.1347
	$\Delta \log E_{t-1}(\beta_{11})$	0.0264	(−0.3544, 0.4071)	0.8919
	ΔOIL_t^* (β_{21})	−0.0051	(−0.0169, 0.0066)	0.3953
	$\Delta DINT_t^*$ (β_{31}) ***	0.0207	(0.0081, 0.0333)	0.0012
	$\Delta TB_t^{Korea*}(\beta_{61})$ *	0.0165	(−0.0026, 0.0356)	0.0889
	Residual standard error	0.0615	–	-
	Multiple R^2	0.4728	-	-
Regime 2 with low-volatility	Intercept (β_{02})	−0.0002	(−0.00192, 0.0016)	0.8242
	$\Delta \log E_{t-1}(\beta_{12})$ ***	0.2586	(0.14525, 0.37200)	0.0000
	ΔOIL_t^* (β_{22}) **	−0.0024	(−0.00461, −0.0002)	0.0291
	$\Delta DINT_t^*$ (β_{32})	0.0018	(−0.00057, 0.0042)	0.1336
	$\Delta TB_t^{Korea*}(\beta_{62})$	0.0012	(−0.00053, 0.0029)	0.1824
	Residual standard error	0.0146	-	-
	Multiple R^2	0.1182	-	-
Transition probabilities	p_{12}	0.0089	-	-
	p_{21}	0.0845	-	-

The response variable is exchange rates. The explanatory variables are oil prices, interest rates and trade balance of Korea. β_{01} and β_{02} are intercepts for regime 1 (high-volatility) and regime 2 (low-volatility). β_{11} and β_{12} are the coefficients of autoregressive terms of exchange rates, β_{21} and β_{22} are the coefficients of oil prices, β_{31} and β_{32} are the coefficients of interest rates, and β_{61}, β_{62} are the coefficients of trade balance of Korea. ***, **, * indicates the 1%, 5%, and 10% significance level, respectively.

3.2. *Japan*

We analyzed the foreign exchange market of Japan which is one of the closest countries to Korea and is quite different in industrial structures and fundamental economic situation. We compared the effects of the six explanatory variables affecting on the exchange rates in the two countries.

3.2.1. Model Selection

According to the model selection method 1 as in Section 3.1, let us select the best model to explain exchange rates in Japan using MRSM. In step 1 of Table 4, the model selection starts with models having only a single explanatory variable from 1(1) to 1(6), where all models include autoregressive terms of the exchange rates. Among the six models with one explanatory variable, 1(4) is the best based on the greatest MLL and smallest AIC, which is the follows:

$$\Delta \log E_t|s_t = \beta_{0s_t} + \beta_{1s_t}\Delta \log E_{t-1} + \beta_{5s_t}\Delta DIPI_t^* + \varepsilon_t|s_t \tag{16}$$

In step 2, all two-explanatory variable models including $\Delta DIPI_t^*$ are tested against model 1(4). In Model 2(5), the trade balance of the US has the greatest $\Delta(-2MLL) = 3.15$, which is not significant. Therefore, the model selection process stops and model 1(4) is the best.

According to the selection method 2, in Japan, we fit the full autoregressive models without regimes and apply stepwise variable selection method based on AIC. In step 1, as shown in Table 5, model 2(1) with ΔOIL_t^* and $\Delta DIPI_t^*$ is selected with the smallest AIC. Then model 2(1) is fitted as a starting MRSM. In step 2, we tried to remove each of ΔOIL_t^* and $\Delta DIPI_t^*$, one at a time. One of ΔOIL_t^* or $\Delta DIPI_t^*$ can be removed since both $\Delta(-2MLL) < 4.61$. We selected the model 1(4) whose MLL is greater and AIC is smaller than those of model 1(1). As in Section 3.1, the two model selection methods resulted in the same best model 1(4). Unlike the selected best model in Korea, the best model in Japan does not include variables such as oil prices, interest rates, and trade balances of Japan or the US.

Table 4. Model Selection Process with Method 1 in Japan.

Steps	Model	Explanatory Variables	AIC	MLL	Criterion
1	1(1)	ΔOIL_t^*	−1562.506	787.253	-
	1(2)	$\Delta DINT_t^*$	−1562.367	787.184	-
	1(3)	$\Delta DCPI_t^*$	−1560.329	786.164	-
	1(4)	$\Delta DIPI_t^*$	−1565.126	788.563	Greatest MLL
	1(5)	ΔTB_t^{Japan*}	−1558.006	785.003	-
	1(6)	ΔTB_t^{USA*}	−1558.189	785.095	-
2	2(1)	ΔOIL_t^*, $\Delta DIPI_t^*$	−1562.192	789.096	-
	2(2)	$\Delta DINT_t^*$, $\Delta DIPI_t^*$	−1563.472	789.736	-
	2(3)	$\Delta DCPI_t^*$, $\Delta DIPI_t^*$	−1563.611	789.806	-
	2(4)	$\Delta DIPI_t^*$, ΔTB_t^{Japan*}	−1563.226	789.613	-
	2(5)	$\Delta DIPI_t^*$, ΔTB_t^{USA*}	−1564.272	790.136	$\Delta(-2MLL) = 3.15$

Every model includes an autoregressive term.

Table 5. Model Selection Process with Method 2 in Japan.

Steps	Model	Explanatory Variables	AIC	MLL	Criterion
1	2(1)	ΔOIL_t^*, $\Delta DIPI_t^*$	−1562.192	789.096	Smallest AIC among all autoregressive models
2	1(1)	ΔOIL_t^*	−1562.506	787.253	$\Delta(-2MLL) = 3.69$
	1(4)	$\Delta DIPI_t^*$	−1565.126	788.563	$\Delta(-2MLL) = 1.07$

Every model includes an autoregressive term.

3.2.2. Empirical Estimation Using the Selected MRSMs

Figure 2 shows the filtered probability of regimes at each time point in Japan. The upper plot shows the filtered probability of regime 1 with high-volatility and the lower plot shows regime 2 with low-volatility. The two probabilities for each time point should sum up to 1. Unlike the apparent high-volatility periods presented in Korea, the plots in Japan do not reveal any prolonged periods in high or low-volatility. For Japan, the transition from high to low volatile regime or vice versa seem to occasionally occur, which is identified in the similar transition probabilities in Table 6. The transition probabilities in Japan are $p_{12} = 0.7417$ and $p_{21} = 0.6372$. The ratio p_{21}/p_{12} is 0.8591 which is less than 1 and much smaller than the ratio in Korea 9.4944. In Japan, the movements of exchange rates tend to tend towards stable market rather than unstable market.

The time points are said to be in regime 1 with high-volatility if its filtered probability of the regime 1 is greater than 0.5. Even though Figure 2 does not show two clear regimes like in Korea, the 1997 Asian financial crisis and the 2008 global financial crisis are still observable in Japan.

Based on the selected model 1(4), we examine how IPIs influence the exchange rate movements in each regime. Table 6 presents parameter estimates, 95% confidence intervals of the estimates, and their p-values. The volatility of regime 1 with high-volatility ($\sigma_1 = 0.0261$) is only 1.66 times that of regime 2 with low-volatility ($\sigma_2 = 0.0157$). In regime 1 with high-volatility, the exchange rate movements are significantly influenced by both the autoregressive terms at 1% significance level and the changes in the IPIs at 5% significance level. In regime 2 low-volatility, none of the six explanatory variables significantly influenced the exchange rate movements. The determination of coefficient R^2 is 0.2858 in regime 1 and R^2 is 0.0020 in regime 2. This means that this MRSMs are better fitted in regime 1 with high-volatility than in regime 2 with low-volatility.

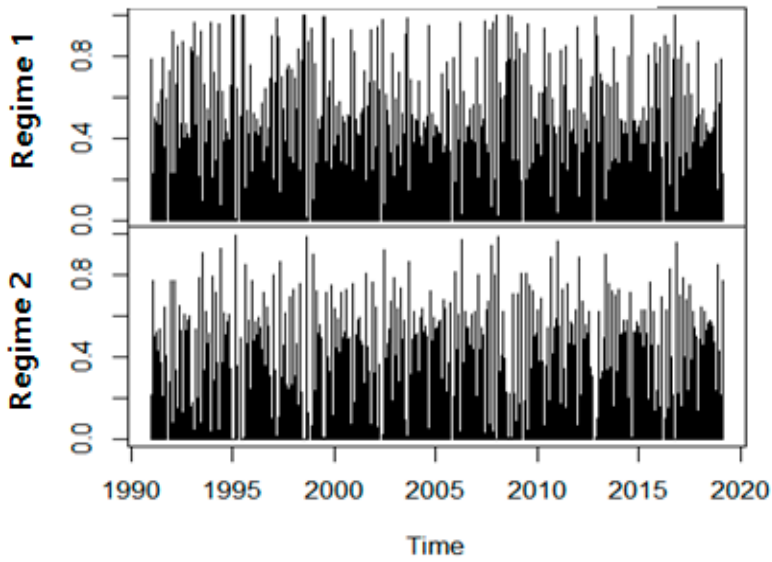

Figure 2. The filtered probabilities of belonging to regime 1 with high-volatility and regime 2 with low-volatility, estimated from the MRSM of the exchange rates along with industrial production indices (IPIs) of Japan. The upper plot shows regime 1 and the lower plot shows regime 2.

Table 6. Parameter Estimates of the Selected MRSM in Japan.

Regime	Parameters	Estimates	95% CI	*p*-Value
Regime 1 with high-volatility	Intercept (β_{01}) *	−0.0048	(−0.0096, 0.0000)	0.0549
	$\Delta \log E_{t-1}(\beta_{11})$ ***	0.6890	(0.4444, 0.9335)	0.0000
	$\Delta DIPI_t^*$ (β_{51}) **	−0.0065	(−0.0127, −0.0003)	0.0422
	Residual standard error	0.0261		
	Multiple R^2	0.2858		
Regime 2 with low-volatility	Intercept (β_{02})	0.0035	(−0.0031, 0.0101)	0.3033
	$\Delta \log E_{t-1}(\beta_{12})$	−0.0027	(−0.0745, 0.0692)	0.9413
	$\Delta DIPI_t^*$ (β_{52})	0.0007	(−0.0035, 0.0049)	0.7389
	Residual standard error	0.0157		
	Multiple R^2	0.0020		
Transition probabilities	p_{12}	0.7417		
	p_{21}	0.6372		

The response variable is exchange rates. The explanatory variable is industrial production index. β_{01} and β_{02} are intercepts for regime 1 with high-volatility and regime 2 with low-volatility. β_{11} and β_{12} are autoregressive terms of exchange rates. β_{51} and β_{52} are the coefficients of industrial production index. ***, **, and * indicates the 1%, 5%, and 10% significance levels, respectively.

4. Conclusions

We examined the effects of oil prices on both Korean and Japanese exchange rates, using the MRSMs and incorporating fundamental economic variables: interest rates, consumer price indices, industrial production indices, and the trade balances of each country and the US. We selected the best MRSM model for each country using two model selection methods and criteria. Using the selected best two-regime MRSM model, we examined the effects of oil price shocks on the exchange rate movements in both Korea and Japan.

In Korea, the selected MRSM includes the exogenous variables: oil prices, interest rates differences between Korea and the US, and the trade balance of Korea. In the selected MRSM model, there were evidences of two distinct regimes in the Korean foreign exchange market, regime 1 with high-volatility and regime 2 with low-volatility. The stable periods of regime 2 lasted longer than the unstable periods of regime 1. The most highly volatile periods occurred during the Asian financial crisis in

1997–1998 and the global financial crisis in 2008–2009. In regime 1 with high-volatility, the exchange rate movements are influenced by the changes in interest rates differences between Korea and the US, and the changes in the trade balance of Korea. The impact of interest rates is greater than the trade balance. In regime 2 with low-volatility, the exchange rate movements are influenced by the changes in oil prices and autoregressive terms. The effect of autoregressive terms is much greater than oil prices.

In Japan, the selected MRSMs include only one exogenous variable, the changes in IPIs differences between Japan and the US. Oil price is not included as an influencing factor on Japanese exchange rates. The two distinct regimes are not observable in the Japanese foreign exchange market. Instead, the two regimes occasionally alternate without a prolonged period. In regime 1 with high-volatility, the exchange rate movements are highly influenced by the autoregressive terms, and the changes in IPIs differences with smaller impact compared to autoregressive terms. In regime 2 with low-volatility, the movements of exchange rates are influenced by none of the explanatory variables.

Comparing Korea and Japan in view of the volatility of the foreign exchange market, when the market is highly volatile, the Korean exchange rate movements are significantly influenced by the changes in interest rates differences and trade balance of Korea. Whereas the Japanese exchange rate movements is based on the changes in IPIs. When the market is less volatile, the Korean exchange rate movements are significantly influenced by the changes in oil prices, whereas Japanese exchange rate movements are influenced by none of the six explanatory variables. Autoregressive terms are significant when the Korean foreign exchange market is less volatile, meanwhile, in Japan they are significant when the foreign exchange market is highly volatile. Oil prices are significant in the stable regime of Korea, but not significant in both stable and unstable regimes of Japan. The Japanese foreign exchange market is more resistant to external shocks caused by oil prices since the Japanese industry and economy is less dependent on oil.

This study provides very important perspectives on exchange rate movements in Korea and Japan. In Korea, maintaining stable oil prices in stable regime contributes to further stabilization of the exchange rates market. Since the Japanese foreign exchange market is resistant to economic shock caused by oil prices, it is important to keep industrial production indices stable during the unstable regime, in order to stabilize Japanese exchange rates.

There are some limitations to this study, exchange rates are affected by interest rates, CPIs, IPIs, and trade balances which are also affected by exchange rates in the backward direction as well. We will leave this backward possibility as a gap for future research. Moreover, this study can be further extended to various other countries that import and export oils. Although China is a major trading partner of Korea and Japan, it was not considered in this study, because it does not have a floating exchange rate that is determined by market forces, as is the case with most advanced economies. The yuan was sometimes permitted to appreciate or depreciate against the dollar, and was also moved to a "managed float" system against major currencies including the US dollar. For this reason, our approach is adequate without China in this monetary model which is based on the relative supply and demand of money. Nevertheless, not considering trade with China could be a limitation of this analysis. In future analysis, it is necessary to consider fluctuations in exchange rates taking into account trade with China.

Our results can provide profound perception for Korean and Japanese policy makers who plan against external shocks. Another beneficiary of our work will be foreign exchange rates dealers who make decisions based on foreign exchange rates speculation.

Author Contributions: Conceptualization, S.K., S.-Y.K., and K.C.; methodology, S.K., S.-Y.K., and K.C.; software, K.C.; validation, S.-Y.K. and K.C.; formal analysis, S.K., S.-Y.K., and K.C.; investigation, S.K.; resources, S.K.; data curation, S.K. and K.C.; writing—original draft preparation, S.K., S.-Y.K., and K.C.; writing—review and editing, S.K., S.-Y.K., and K.C.; visualization, S.-Y.K. and K.C.; supervision, S.K. and K.C.; project administration, K.C.; funding acquisition, S.K., S.-Y.K., and K.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by 2018 and 2020 Hongik University Research Funds.

Conflicts of Interest: The authors declare no conflict of interest.

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